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EARLY TERRESTRIAL CONDITIONS THAT MAY HAVE FAVORED ORGANIC SYNTHESIS

THERE is a wide gap between the inorganic carbon compounds, as we now know them in nature, and the much more highly complex carbon compounds which are the material basis of living beings. It is a prevalent view that this gap can not be bridged by natural processes under existing conditions. On the face of things this view seems to be supported by the testimony of experience. This experience, however, when critically examined, is not altogether conclusive. Even if it could be shown beyond question that the chain of carbon compounds necessary to bind the inorganic to the organic never is built up under present conditions, there would still remain a legitimate ground of doubt in the possibility that this may be due to predaceous plants and animals, especially bacteria, which attack the carbon compounds at the first stages at which they become available for food and thus cut off the evolving series before it is complete. In this it is assumed that the formation of the more complex carbon compounds can come about only as the result of a long series of synthetic steps, and that at some of these stages, probably at many of them, the products would be suitable food for existing beings, especially for the almost omnivorous and ubiquitous bacteria. This prolonged evolution may thus be regarded as an extremely precarious process in the presence of predatory organisms; may indeed be regarded as practically prohibitive

after the earth was once well planted with the rapacious varieties. This adverse contingency obtains quite irrespective of the theoretical possibility of such an evolution under favorable conditions, if left undisturbed.

A further element should not be overlooked. Before an organic series can be permanently assured, the power of self-propagation must be acquired. What may be the contingencies attending the addition of the self-propagating function to the acquisition of the requisite chemical constitution is at present quite beyond determination. There may be in this supplementary process, if indeed it be a supplementary process, as great a liability to predatory arrest, as in the chemical synthesis itself. Probably the safest answer which the extreme evolutionist can give to the suggestive question why wholly new orders of living beings have not appeared at frequent intervals in the geologic record, lies in an appeal to the rapaciousness and universality of the attack of organisms already present.

It is merely as a matter of precaution that these considerations are cited here. It does not seem to us safe to make the unqualified affirmation that present terrestrial conditions are wholly incompatible with the natural synthesis of a series of carbon compounds linking the inorganic to the organic if the whole predaceous kingdom were removed so as to leave the organizing agencies unlimited opportunities for interaction for an indefinite period. The purpose of this paper is not to meet a geologic necessity, but merely to consider those conditions in the early history of the globe which may be thought to have been specially favorable to organic synthesis, irrespective of the question whether the natural evolution of life was wholly dependent upon them or was merely facilitated by them. The paper is not the result

of an inquiry into the problem of organic synthesis, as such, but is rather a preliminary statement of supposed geologic conditions intended to suggest inquiry in certain lines which do not seem to have been critically pursued. At the same time, the treatment may serve to connect with this chiefest of synthetic problems the postulates of the planetesimal hypothesis which have been little discussed in this regard.¹ Only a part of the agencies herein suggested as bearing on the synthetic process are however peculiar to this hypothesis. In some notable part they are assignable to any mode of origin which the earth may reasonably be supposed to have had.

The growth of the earth by the planetesimal method leaves a rather wide speculative range relative to the conditions which prevailed at the stage when life was introduced. At the same time, the hypothesis recognizes limitations which shut out certain conditions that have sometimes been thought to be important to the evolution of the higher carbon compounds, notably high atmospheric pressure. Under the older cosmogonies very high atmospheric pressures associated with very high temperatures were postulated. Under the planetesimal hypothesis, it is indeed possible and logical to assign to the atmosphere as great an extent and as high a pressure as the gravity of the earth can control; but the hypothesis, as we hold it, is built on the assumption that molecular activities limit the atmosphere, a principle which, if true, limits it under any hypothesis. If the doctrine of Stoney, modified to meet the new advances in physics, is sound, it can not, of course, be violated by any cosmogonic hypothesis without self-destruction. If this doctrine is true, and the earth-mass lacks power to control an

¹ Chamberlin and Salisbury's "Geology," Vol. II., 1906, pp. 111-116.

atmosphere radically greater than the present one, it is obvious that the notion of an atmospheric pressure appreciably greater than the present should not be entertained. It is because this doctrine of Stoney is believed to be fundamentally sound, subject to some qualifications, that the planetesimal hypothesis has developed its postulates in consonance with it and has not consciously entertained assumptions regarding sequential states that are at variance with it. If the doctrine of Stoney is sound, the gaseous and gaseo-meteoritic hypotheses have no advantage as to the pressures of the early atmospheres; on the contrary, the higher temperatures they assume imply greater molecular activity and hence greater molecular losses and less pressures than prevail around the present relatively cool earth. In this paper, therefore, no appeal will be made to *general* atmospheric pressures appreciably greater than the present; indeed, we shall try to be true to the assumption that the *general* atmospheric pressures in the formative stages of the earth were lower rather than higher than they are at present. What volume of atmosphere and what degree of atmospheric pressure may have been compatible with the gravitative power of the earth at such early stages as were first suitable for the evolution and preservation of organic compounds is not yet definitely postulated by the planetesimal hypothesis. It is merely assumed that a suitable atmosphere, hydrosphere, temperature and other conditions were found at some one of the progressive stages leading up to the present state and that there was a gradual transition from that stage to the existing state of things. So far as gravity alone is concerned, a sufficient atmosphere and hydrosphere might apparently be held when the earth had about one tenth its present mass, *i. e.*, about the present mass of Mars, which ap-

parently holds an atmosphere and perhaps a hydrosphere.

If the earth were formed by a gathering of planetesimals into a nucleus which at an earlier stage was one of the nebulous knots of a spiral nebula, the value of the mass at the time it first became a solid body should have hung upon the ratio of the original knot to the scattered nebulous matter destined to be gathered into it, concerning which there is little to guide opinion. In this uncertainty, let it be assumed that at the stage when the growing earth was ready for the critical synthesis, its mass lay somewhere between one tenth and three fourths of the present mass, and that the mass of the early atmosphere held a proportionate ratio to the mass of the existing atmosphere. Let it also be assumed that at the time at which the hydrosphere began to gather about the globe, the earth's surface was formed of a heterogeneous, uneven, talus-like mantle, such as the infalling planetesimals would naturally produce, and that this constituted a deep porous zone. Until the hydrosphere was added there was a lack of efficient solutions and inwash to cement the fragmental material. The hydrosphere, in its first stages, must have occupied the lower part of this porous zone, and must have crept upwards as its volume increased. It should have appeared at the surface first in the bottoms of the deformation sags, the innumerable craters and the other depressions, and as it gradually extended itself, it must have linked more and more of the isolated water-bodies together. Throughout the earlier stages of growth, the prevailing aspect should have been that of innumerable small water-bodies scattered over the face of the land, rather than that of the great confluent ocean of to-day.

This then is the general physiographic setting which the planetesimal hypothesis, at least in one of its phases, presents for

the initiation of the chemical synthesis to which is assigned the task of bridging the gap between the inorganic and the organic compounds.

So far as chemical reactions of the familiar inorganic class are concerned, such a stage of earth-growth must obviously have presented conditions favorable to unusual activity, since the contact surfaces between the atmosphere and the hydrosphere, between the hydrosphere and the rock surfaces, and between the atmosphere and the rock surfaces, were all relatively large and varied, while the temperatures produced by the radiation received from the nebulous sun and by the heat of impact of the planetesimal matter may be presumed to have given a varied range of thermal conditions. As a result, reactions of exceptional variety should have been developed. In view of the vast number of bodies of water and their varied contacts with all sorts of rocks, together with the possibilities thus presented for the isolation of special combinations in their early stages and the correlative possibilities of conjunctions and minglings of these in their subsequent stages, there may well have resulted numerous diverse chains of sequences.

At that stage the atmosphere should have held each of its present constituents but probably not in the same proportions as now. The elements of lower specific gravity should have been smaller in amount relatively than at present, while those of higher specific gravity should have been more abundant relatively, because the controlling power of the smaller earth limited the range of molecular retention. Relative to the lighter constituents, it need only be added that, instead of escaping completely from the control of the earth, as postulated in the earlier phases of the doctrine of Stoney, the lighter molecules should in the main have

escaped merely into the supplementary orbital atmosphere, where they might have persisted for long periods during which they were always subject to being driven back to the earth by occasional encounters, so that, although these constituents may have been rare in the denser collisional atmosphere near the earth's surface, they were doubtless present in sufficient amounts to have participated in any appropriate chemical synthesis. It is to be added further in qualification of this that, with the exception of hydrogen, which might have been derived from its compounds, the lighter atmospheric constituents, such as helium and neon, are chemically inert and there is no specific reason for supposing that they entered into any stage of the organic synthesis. The heavier constituents of the early atmosphere would include the compound gases of carbon, nitrogen, sulphur and phosphorus.

During the critical stages of growth, the infalling of planetesimals is supposed to have continued to be active. The planetesimals are assumed to have contained carbon, sulphur, phosphorus and all other elements found in organic matter; and as they impinged more or less violently upon the surface formed of previous accessions of similar matter, there should have been generated various compounds of these elements. A portion of these compounds should have been gaseous or vaporous and should have been variously disseminated into the atmosphere, or else absorbed into the waters or into the porous earthy mantle. The volcanic action of the period should have contributed its characteristic constituents in similar variety of combination. It may therefore be assumed with plausibility that a larger percentage and a greater variety of volatile compounds of the critical class prevailed in the air, subject to absorption into the earth-mantle

and the waters, during the stages of active terrestrial growth than at the present time, when terrestrial activities have more largely settled down into a state of less disturbed equilibrium. The same may doubtless be presumed of the unstable non-volatile compounds of the critical elements, but just here we are considering only the factor which worked through the atmosphere.

We have already denied ourselves any special appeal to *general* atmospheric pressure as an agency of the particular synthesis in question, but in doing this we have limited our abnegation to the sum total of pressure. It is still pertinent to inquire what may have been the effects of *partial* pressure. Starting with the familiar postulate that each constituent of a mixed gas acts in accordance with its own individual partial pressure, it appears that high partial pressures of the *critical* constituents should have been more effective in causing their entrance into combination than high general pressure without such high partial pressures. We have just seen that the chemical and physical conditions attending the stages of active earth-growth might well have given rise to large proportions of the critical compounds. By extending the argument it is not difficult to see that the actual amount of the carbon, sulphur, phosphorus and nitrogen gases might have been sufficiently greater than now to have promoted their union, for they all have high specific weights and could be held in relatively large proportions by the gravity of even a small earth. The gaseous compounds of nitrogen have a place in this class, though the free nitrogen was probably less abundant than now, but since free nitrogen is organically inert, it is negligible except as a source of its compounds.

If we turn to the non-volatile or slightly volatile compounds of the critical ele-

ments, we find, as already remarked, reason for thinking that there may have been more of the unstable compounds of this class than now, for secular progress would be in the direction of chemical stability. There are certain probable sources of unstable compounds of carbon, sulphur, phosphorus and nitrogen which call for special notice. Planetesimals are only one form of meteoroids and it is possible that the meteorites which reach the earth in appreciable masses may not often be true planetesimals of the class supposed to have formed the earth, but if the theory of common meteorites advanced by the senior author be the true one,² the compositions of the two classes are probably much alike, for according to this theory meteorites are supposed to be the fragments of small planetoidal bodies which have been disrupted by close approach to large bodies. These planetoidal bodies are supposed to have been too small to hold atmospheres and hydrospheres, and hence the planetesimals which formed them were never subjected to atmospheric and hydrospheric agencies, and hence they retained their planetesimal constitution with little modification.³ This furnishes ground for assuming that the compounds found in meteorites were also present in the planetesimals. This presumption finds support in the nature of the case, for the gases shot forth from the sun to form the planetesimals probably were much dissociated by high temperature at the instant of emerg-

² *Astrophys. Jour.*, Vol. XIV., 1901, pp. 17-40; *Jour. Geol.*, Vol. IX., 1901, p. 369, and Chamberlin and Salisbury's "Geology," Vol. II., pp. 22-38.

³ Dewar states that at a temperature of -130° C. liquid oxygen has no chemical action on hydrogen, potassium, sodium, phosphorus, etc. (*Proc. Roy. Inst.*, Vol. 11, 1884-6, p. 550), and this is perhaps an additional reason why planetesimals and meteorites enveloped in the low temperatures of space prevalent at considerable distances from the sun have been subjected to little oxidation.

ence and later combined in all available ways as they met appropriate elements at the various lower temperatures through which they passed in the course of their cooling.

Meteorites contain a very suggestive series of compounds of the essential elements, carbon, oxygen, nitrogen, hydrogen, sulphur and phosphorus. Among these compounds it is especially interesting to note that several are unstable under the usual conditions that prevail at the surface of the earth. Among these are the phosphide, schreibersite, the sulphides, troilite, daubréelite and oldhamite, the carbide, cohenite and the chloride, lawrencite. These unstable compounds are sometimes intergrown or otherwise closely associated with one another, so that the products of any reactions that may grow out of their instability are favorably located for reaction upon one another, and such reaction is liable to arise when the celestial equilibrium is disturbed by terrestrial conditions. There is also present a form of graphite which oxidizes more rapidly than terrestrial graphite. Such graphite, as well as amorphous carbon, is intergrown with the unstable sulphide, troilite, and the unstable phosphide, schreibersite. The readily oxidizable graphite sometimes contains within itself sulphur and hydrocarbons. Roscoe extracted from a meteorite a hydrocarbon which contained sulphur.⁴ Clôez and Pisani found in the Orgueil meteorite matter of the organic type which had a composition closely similar to terrestrial humus, viz., C, 63.45; H, 5.98; O, 30.57.⁵ Lawrence Smith also extracted hydrocarbons from meteorites, among which was a compound of carbon, hydrogen and sulphur having approximately the composition of $C_4H_6S_4$; also one which he

formulated as $C_4H_6S_5$.⁶ Ansdell and Dewar favor the view that the hydrocarbons had their origin in carbides, a view supported by the observed presence of carbide in meteorites.

It may be assumed that the graphite resulted from the action of water, gases and other agents, on the carbides of the metals, and that during the chemical interactions which took place, a portion of the carbon became transformed into organic compounds.⁷

The hydrocarbons in meteorites embrace, according to Cohen, compounds of carbon and sulphur; of carbon, hydrogen and sulphur; and of carbon, hydrogen and oxygen, respectively. The hydrocarbons sometimes have a resinous or waxy aspect, and on decomposition may give an oil of bituminous or fatty odor. The compounds of carbon, hydrogen and oxygen afford extracts resembling peat, humus or lignite. All the alkalis, and all the earthy and metallic constituents which are essential to plant life are present in meteorites in variety and abundance. Besides the solid minerals, the gases carbon dioxide, carbon monoxide, methane, hydrogen, nitrogen and sulphuretted hydrogen are either present or are susceptible of development by moderate heat such as the infalls would inevitably produce.⁸ It will be noted that these embrace the more common gases associated with ultimate organic reactions.

The chief point of interest here is not simply the presence, but the close intergrowth, of compounds of the organic elements in states of combination which, while stable in the cosmic regions surrounding the earth from which the planetesimal material was gathered, are pronouncedly

⁴ *Am. Jour. Sci.*, 1876, pp. 388-95, also 433-42. Many suggestive details.

⁷ *Proc. Roy. Inst.*, Vol. XI., 1884-6, p. 549.

⁸ For details see "The Gases in Rocks," R. T. Chamberlin, Carnegie publication No. 106, Washington, 1908.

⁴ *Proc. Phil. Soc. Mon.*, 1862.

⁵ *Compt. rend.*, Vol. 59, 1864, pp. 37, 132.

unstable in the presence of the air and water, even at the ordinary temperatures at which organic synthesis takes place. On reaching the surface of the earth, these compounds would therefore have been no longer stable, but must have sought new relations. The transfer from the one state to the other may well have been accompanied by combinations not likely, or at least less likely, to arise under modern conditions of greater stability.

As already noted, a carbide of iron, nickel and cobalt is found in meteorites. The conditions attending the formation and infall of planetesimals encourage the belief that a wide range of carbides, and probably also of nitrides, may have existed among the accessions to the growing earth. But whether the amount of such material was large or small, it is clear that, as it was borne to the earth in the divided state of planetesimals, its measure of contact with the moisture of the surface was exceptionally large and hence the suggestive reactions which follow under these conditions should have been large in proportion to the amount of carbides and nitrides present. Even with cold water, the carbides of barium, strontium and calcium give rise to acetylene, while the carbides of aluminium and beryllium generate methane. Under the same conditions, uranium carbide gives rise to a gaseous mixture of methane, hydrogen and ethylene, and in addition to this generates considerable quantities of both liquid and solid hydrocarbons.⁹ While nitrides are not known to furnish directly such a varied assortment of gases, they may readily give rise to ammonia gas under various conditions. Iron nitride, heated to 200° C. in the presence of hydrogen sulphide, yields iron sulphide, a sulphide of

ammonium, and free hydrogen ($2\text{Fe}_2\text{N} + 6\text{H}_2\text{S} = 4\text{FeS} + 2\text{NH}_4\text{HS} + \text{H}_2$).¹⁰

It is impossible to follow the remoter reactions which might spring from these various first products of the carbides and nitrides by further interaction, but it is to be noted that all the new products, *if closely associated*, as the conditions of the case imply, were liable to meet one another while in the state of nascent activity, or in such stimulated activity as may attend previous activities, however this may be interpreted. Reaction might also have been aided by the catalytic relations into which these products came in their intimate association with the débris of the surface, with one another and with the new accessions added constantly to the earth's surface.

As already noted, the superficial portion of the growing earth is supposed to have been a loose, incoherent aggregate of highly fragmental planetesimal matter, and this was subject to weathering and various forms of comminution. The resulting porosity may have led to the condensation of much of the gaseous matter within its capillary and subcapillary pores, as soils are known to do at the present time. The graphite and amorphous carbon may have acted somewhat after the analogy of charcoal which is well known to absorb certain gases to a phenomenal extent. Various porous substances, including earths, possess this property of gas-condensation in appreciable degrees. Not a few metals also possess, irrespective of porosity, certain occlusive affinities or selective powers of absorption for certain gases, as palladium and platinum for hydrogen, etc. While the efficiency of charcoal is clearly due in large part to its extreme porosity, it is doubtless due in part also to the substance itself, for coal manifests a somewhat similar property. Fresh coal rapidly absorbs oxygen from the

⁹ Moissan, *Proc. Roy. Soc.*, Vol. 60 (1897), pp. 156-60.

¹⁰ Fowler, *Jour. Chem. Soc.*, Vol. 79, p. 297.

air, condensing it within the pores and crevices; but because of its activity in this condensed form, the oxygen soon unites with the substance of the coal and passes on to chemical union, making room for the absorption of more oxygen from the air.

Pursuing the phenomena of charcoal further by way of illustration, the well-known fact may be recalled that a layer of charcoal spread over decaying organic matter permits it to waste away gradually without giving off offensive odors, owing to the fact that the gases and the volatile products of the decomposition coming in contact with the charcoal are drawn into its pores and there oxidized by the condensed oxygen which the charcoal has absorbed from the air. Owing perhaps to a sort of catalytic action, the oxygen condensed in the pores of the charcoal becomes more active than the ordinary oxygen of the air. While charcoal furnishes the most declared case, soils and comminuted earth matter are known to possess similar properties in a notable degree.

In summation, we conclude that the porous mantle of the earth thus supplied by planetesimal infall with unstable carbides, nitrides, phosphides and sulphides undergoing transformation into more stable compounds, and generating during this process hydrocarbons, ammonia, hydrogen phosphide and hydrogen sulphide gases mingled with the ordinary gases carried by the planetesimals, furnished rather remarkable conditions for interactions and combinations, among which unusual syntheses would not be improbable.

If, with these special possibilities in mind, we turn to the question, what physiographic situation on the surface of the early earth presented the most favorable conditions for the organic synthesis, three general views offer themselves as alternatives, and under one of these there is a

localization so specific as to have the force of a fourth view. The primitive organic synthesis may have taken place (1) in the ocean, (2) in some body of fresh water, or (3) on the land, or, more specifically, (4) in the soil. By soil in this connection is meant merely the earthy mantle of comminuted and weathered material; the absence of organic matter at the outset is of course assumed.

May we not take it for granted that the higher presumption will lie in favor of that localization which brings into closest interaction the requisite material in unstable states, attended by the maximum range of concentrations, condensations, catalytic, electrical, nascent and other favoring conditions?

If planetesimals carrying the essential constituents in unstable forms fell into large and deep bodies of water, the soluble and gaseous products of such reactions as followed would have been likely to be widely diffused and diluted, would have received little aid from the catalytic action of rock or earth material, would have been unassisted by soil porosity, and would have been but little favored by concentrations except such as involved an increase of density of all the constituents held in the water body whether favorable, hostile or indifferent in nature. Organic synthesis at present clearly involves a series of very special selections of material from among a miscellaneous association, the larger part of which is either neutrally obstructive or hostile. In the case of a completed organism, provided with the proper selective appliances, the requisite material may be gathered from such a dilute intermixture of the essential and non-essential materials as the water-bodies present, but until these selective appliances are provided, the water-bodies seem to us to be deficient in some of the most propitious conditions.

In the absence of such organic selective structures at the outset, it may be worth while to look for inorganic agencies that may perhaps have performed in a crude way the functions which the organic structures came later to perform in a much superior way. It is not clear that a selective concentrative agency can be found in the large water-bodies, independent of life, for their tendency is diffusive and equalizing rather than concentrative. Can it be found in the soil?

To form a definite picture of the conditions which may have been presented by certain soils, let a foreland lying between extensive uplands and a permanent water-body of appropriate salinity be chosen as a concrete example. In such a situation a constant water-level should have prevailed not only at moderate but at graded depths beneath the surface. The underground water should have received accessions percolating basinwards from the uplands bearing whatever soluble materials the uplands could furnish, while, on the other side, there should have been waters percolating landward from the water-body bearing such salinity as it possessed, while more or less spray from the water-body was scattered by landward winds over the surface and fed the soil from above. The measure of water-movement in the one direction or the other must obviously have depended on the balance between the precipitation and the evaporation on the adjacent land which varied with seasons and localities. The underground waters thus supplied by the slightly fluctuating water-table should have been carried up by the capillary passages of the soil to horizons of evaporation and concentration at or near the surface. The graded depth of soil above the water-table should have furnished unlimited adaptations to the porosity of the soil-mantle and to the meteorologic conditions of the seasons and the special situations.

The horizons of concentration by capillarity and by evaporation were affected by all degrees of insolation from direct sunlight, at the immediate surface, to all measures of shadowing below, furnished by the soil itself. The substances deposited within the soil and the substances leached from it, alike modified its porosity in their own special ways, and such deposits as were formed in the soils should have developed porosities of their own. Isolated cells and tubes may thus have been formed by travertine and similar deposits in the pores of the soil. As already implied, the capillary feeding from the water-table, when the balance set that way, and the partial evaporation of the solutions within the pores of the soil near or at the surface, must have produced concentrations of the non-volatile substances carried by the capillary waters into these upper horizons. Between these upper concentrated solutions and those below there should naturally have followed inter-diffusion and osmotic action, and thus there should have sprung up in the soil a circulation somewhat analogous to that of the plant; indeed, it may not be going too far to suggest that this circulation within the soil is more than a simple analogue of the systematic circulation which is definitely organized in the plant structure; it may possibly be its genetic forerunner. The larger cavities within the soil were inevitably connected by constricted passages which were liable to be partially or wholly filled with porous precipitates or with inorganic colloids, and these chains of pores might thus come to serve a circulatory function which was an actual precursor to that circulation from cell to cell through membranous walls which distinguishes compound plants. It is even more probable that the circulation within an earth-pore, partially isolated from adjacent earth-pores containing solutions of different density, might develop a circulation closely like that

of unicellular plants. A constant evaporation at the surface might perpetuate the differences of density sufficiently to continue the circulation for the requisite period. So, on the other hand, if the ground waters were sufficiently saline, the periodic accession of fresh water at the surface might give, in reverse order, density-differences sufficient to perpetuate circulation.

Whether analogy may be pushed so far as this on substantial grounds or not, it is obvious that the soil presents a suggestive assemblage of conditions favorable to chemical synthesis, and that these deserve a critical attention which the limits of this paper forbid us to try to pursue into fuller detail. It is clear that under these conditions evaporation was permitted to develop the greatest variety of concentrative effects which can well be assigned to it, and that at least some facilities were offered for the perpetuation and modification of these concentrations when once established. It is obvious that in the soil there might have been any degree of exposure of the reacting substances to light within very small differences of depth, and that there was easy intercommunication and commingling of the different products of such photosynthesis by means of capillary circulation. It is obvious that in the soils there might have been found the full range of capillary dimensions from coarse tubes and pores down to the limits of sub-capillarity with the full gamut of condensation-effects assignable to these. The same may be said of all catalytic effects referable to the relations of the solids and solutions concentrated in the soils.

An important class of chemical reactions observed in the matured plant of to-day takes place within the organism without much obvious addition or loss of material, apparently an internal readjustment of

matter under its own stimulus. This is familiarly seen in the maturing of seeds after they have been separated from all connection with the plant circulation, in which little external change beyond some possible loss of moisture is observable. In many cases, germination will not take place at once; a period of internal organization or ripening must intervene. This thus represents a last stage of preparation for self-propagation, or, in other words, the last stage of an advanced phase of organic synthesis. It may not accord with conventional usage to call this self-catalytic action, but in some way it seems to be due to stimulus which the partially organized materials exert on one another and by which they thereby push farther forward the synthetic process. The prevalence of this internal action in the last stage of the organic cycle suggests that analogous action may occur far back in the synthetic series, and that much of the more complex part of the cycle may perhaps be accomplished by such action, conditioned like it on the confinement of the partially organized material in a cell-like cavity where it was subject to accessions of the sustaining solutions and to concentrations by the removal of water and volatile matter. If this speculative conception be warranted at all, the quasi-cellular structure of the porous soil might not inappropriately be conceived as serving the function of a rude inorganic husk, or shell, abetting by confinement and protection the internal synthesis of its contents.

If we may appeal to still other agencies whose functions are as yet imperfectly understood, the electrolytic action of earth-currents may be worthy of mention. It is well known that saline waters are better conductors of electricity than fresh waters or dry earth, and hence it is probable that the restoration of electrical equilibrium on the earth's surface after it has suffered dis-

turbance may be attended by electrical passages between the saline water-bodies and the land tracts. There are reasons for believing that electrical interchanges were more active in the growing stages of the earth than at the present time when the solar system may be presumed to have settled down into a condition nearer equilibrium. The planetesimal matter circulating about the planetary nucleus and the sun, and between them, probably served both to disturb the electrical status of these bodies and to afford a means of electrical communication between them and the planetesimals. Under electric laws, planetesimals charged with electricity and circulating at high velocities about the young planet should have had the effect of electrical currents, and should have generated magnetic fields about the magnetizable matter of the earth; and these magnetic fields, in turn, should have modified and perhaps controlled the paths of electrons and ions traversing these fields. It is beyond the scope of this paper to try to follow these into detail, and it may suffice to merely indicate that electrolytic action stimulated by electrical currents traversing the surface may fairly be presumed to have played a more active part during the nebular stages than they do to-day, whatever that part may be.

On similar grounds, it may be suggested that the agitations of radioactivity, and the states of ionization to which it gives rise, may have played a slightly more active part in the chemical processes of early times than they do to-day, whatever that may be, because of secular decay.

Some suggestions respecting the original localization of terrestrial life may be derived from a study of the localizations of to-day. The more primordial types of the vegetal life of the mid-ocean are limited in variety and in susceptibility to variation.

In the judgment of some of our most trusted botanists, pelagic vegetal life does not present pronouncedly the qualities which imply germinal or evolutionary power. A similar statement may be made, with qualifications, relative to the life of the larger fresh-water bodies. In the shore tracts, indeed, there is greater variety of life and greater indication of germinal competency, but even here the forms which lie nearest the hypothetical primitive types do not give signs of conspicuous evolutionary potency. On the other hand, the plant life of the land presents much greater variety of form and of organization, and greater signs of germinal virility.

If we may judge of the fitness of soils to serve as a nidus of organic genesis, by the life it fosters to-day, a favorable verdict seems warranted by the remarkable assemblage of low forms which make the soil their habitat and which manifest peculiar adaptations to their earthy conditions and to one another. There are not only a host of simple forms in which photosynthesis plays its usual part, but forms that flourish quite irrespective of sunlight; there are not only species that use carbon dioxide and require oxygen, but species that live quite without free oxygen, and even find it a hostile element; there are forms that oxidize sulphuretted hydrogen and use the energy thus derived for their activities, and there are forms that oxidize ferrous to ferric iron to like ends.¹¹ Some of the sulphur-bacteria seem to combine the generation of energy from sulphuretted hydrogen with the more common mode of oxidizing carbon compounds, thus uniting in a suggestive way independent chemical processes. There are also bacteria that oxidize free nitrogen into nitrites and others that promote the formation of nitrates. The rich

¹¹ Jost's "Plant Physiology," Gibson's translation, 1907, pp. 220-31.

realm of soil life seems yet far from being exhausted by research either in respect to the range of forms or the scope of their chemical activities, but it is at least clear that the soil is the foster-ground of remarkable biochemical activities. Some large part of such activities is dependent on preexistent organic matter and is in no sense initial, but in a significant part of it, organic compounds do not seem to be prerequisite. This variety of action and these peculiarities of the life of the soil-mantle are at least suggestive of genetic conditions.

If we seek for such uncertain light as the geological record may throw upon the habitat of the first life, we are confronted by the fact that the record makes only a very distant approach to the real genesis of life. If we permit ourselves to reason from the nature of the Proterozoic formations, we find grounds for a belief in a very early mantling of the land surface with vegetation.¹² A study of the early habitat of some of the leading forms of life seems also to favor the land or the land-waters.¹³ While these geological considerations have their obvious limitations and may seem to be too far removed from the specific question of organic synthesis to have much value, they may at least be permitted to serve as an offset to the prepossessions which seem heretofore to have obtained widely in favor of the origin of life in the ocean. They may also help to bring into equitable competition the view that primitive organic synthesis may have found its genetic conditions in some of the lowland soils on the borders of the permanent water-bodies.

¹² Chamberlin and Salisbury, "Geology," Vol. II., pp. 139, 199, 302.

¹³ Chamberlin, "The Habitat of the Early Vertebrates," *Jour. Geol.*, Vol. VIII., 1900; Sardeson, "The Phylogenic State of the Cambrian Gastropods," *Jour. Geol.*, Vol. XI., 1903; Chamberlin and Salisbury, "Geology," Vol. II., p. 480.

The original organic process was undoubtedly vegetative rather than animal in type, *i. e.*, the primitive organisms increased the sum total of organic matter and stored energy in it. The store of energy attained by any given plant consists (1) of that which it inherits with its spore, seed or germinal part and (2) of that which it adds thereto from terrestrial and cosmic sources of energy. If the plant feeds wholly on carbon dioxide, water, nitrates, sulphates, phosphates and similar *wholly oxidized* compounds, its sources of free energy are essentially limited to two classes: (1) radiant energy, derived chiefly from the sun and allied sources, and (2) chemical energy, derived from the oxidation of a portion of the germinal matter. The peculiar cooperation of these two sources of energy forms a distinctive combination. A part of the energy set free by germinal oxidation cooperates with the remainder and with solar energy to build up additional complex compounds. This new complex matter is built up from fully oxidized material by deoxidation combined with a synthetic process which gives it higher complexity. This process obviously requires additional energy. The synthetic function resides primarily in the germinal matter, for the formation of new compounds may proceed to certain lengths without sunlight; but the main source of the energy required for deoxidation resides in the sun. The germinal matter thus seems to have two phases of action: (1) simple oxidation, which gives free energy for its own activities, and (2) synthetic stimulus, by which complex carbon compounds are organized. This last takes place at the outset by the transformation of its own substance, but later, with the cooperation of sunlight, by the synthesis of simpler substances previously in a fully oxidized state.

Now, if any inorganic matter is to take

the place of this germinal matter in synthesis, it must apparently subserve this double function of suffering oxidation of a part to yield the energy required to organize its remaining part into other complex compounds. This peculiar double function seems to furnish a criterion which must probably be met, if we are to find in early terrestrial history any inorganic agency which may have subserved crudely the synthetic function which has since been developed so extraordinarily by self-perpetuating organic agencies. Are there any agencies among those previously under review which act in any such way, and which might be supposed, even by the license of hypothesis, to serve as a crude substitute or forerunner for the germinal matter?

Before trying to answer this crucial question, let another characteristic of organic matter as a source of energy be noted. The energy which can be derived from living matter by oxidation is distributed among many atoms, or, if it be interpreted as concentrated in certain of the atoms among the complex assemblage, it is so diluted or distributed by the neutral atoms present that its effect is distributive. *The end secured by this is a slow—perhaps one may say a controlled—use of energy in oxidation distributed over a prolonged period.* The organism is indeed a thermal engine, but its temperature is phenomenally conservative, uniform and sustained, and its consumption of fuel in any unit of time is small. At the same time its constructive work, both of material and of energy, is so much more conspicuous than its consumptive work as to almost completely mask the latter. This distributive conservative action is perhaps the key to the successful absorption and utilization of the mild but pervasive energies of cosmic origin which furnish the increment of energy necessary

to increase the sum total, notwithstanding the portion expended.

Now if we gather together the essentials of the energy processes previously cited as probably present in the primitive days of the earth, shall we find in them any analogues of this cooperative, controlled and constructive process?

Summarizing these essentials in terms of energy, it appears (1) that several of the elements that take part in organic activities were probably present at the outset in a free state and capable of yielding their maximum of energy by oxidation, such as graphite, amorphous carbon, and perhaps sulphur, together with the free gases, hydrogen, nitrogen and oxygen; (2) that there were probably present simple binary compounds such as the carbides and nitrides, which were capable of reacting with water and of setting energy free, and at the same time generating somewhat more complex compounds; (3) that there were hydrogen compounds susceptible of oxidation with liberation of energy, such as the hydrocarbons, ammonia, sulphuretted and phosphoretted hydrogen; (4) that there were partially oxidized compounds susceptible of further oxidation with a liberation of energy, such as the nitrites and ferrous salts; (5) that there were fully oxidized compounds, end products, such as carbon dioxide and water, from which, *by the expenditure of energy*, the carbohydrates might hypothetically be derived by deoxidation and combination; as well as such end products as nitric acid, nitrates, sulphates and phosphates from which, in combination with the preceding, proteids and the nitrogenous group generally might, hypothetically, be compounded; (6) that there were abundant supplies of potassium, calcium, magnesium and silicon in combination from which these elements could be derived by similar means; (7) that there was

abundant diffuse energy in sunlight and other forms of solar radiance, and (8) there were pervasive free energies in states of ionization, in earth currents and in local electric potentials. In short, it appears that there was a group of oxidizable substances which might give up energy by combination, but not in indefinite amounts; that there was an ample supply of substances already oxidized to the full, but which could be partially deoxidized and combined hypothetically to give the complex organic compounds, but only at the expense of energy. A continuous source of pervasive, diffuse energy was afforded by sunlight and other forms of solar radiance, perhaps aided by molecular agitation through ionized states, diffuse electric earth-currents, and local electric potentials; and these sources were ample to meet the requirements of the case.

Recalling the combination of functions required, the most plausible suggestion is offered by the cooperation of the unstable carbides, nitrides, sulphides and phosphides with moisture, sunlight and allied agencies.

Somewhat after the analogy of germinal matter, certain metallic carbides react at ordinary terrestrial temperatures on the accession of water, freeing energy and raising the temperature, but retaining a portion of their power of oxidation and at the same time forming carbon compounds of slightly more complex nature. The phenomena of polymerization may intervene in some cases and favor complex compounds. Some of these compounds are unsaturated, and by additions and substitutions may lead on to other complexities.¹⁴ If the reactions of these carbides took place in the presence of the associated unstable nitrides, sulphides, phosphides and chlorides, there is reason to believe

¹⁴ Moissan, "The Electric Furnace," translation by Moulpiéd, pp. 244 and 256.

that more complex results would follow, involving other organic elements. Experimental results do not greatly help on this point, because high temperatures, strong reagents and artificial conditions have usually been employed in forming the more complex compounds of the organic elements. Violent agencies and extreme conditions are excluded from organic action, and hence presumably from any antecedent action closely precedent to it. In the case in hand, combination could be abetted by evaporation, by porous condensation, by selective concentration, by catalytic action, by confinement in pores, cells and ducts, by capillary and osmotic action, by genial temperatures, by sunlight and by allied agencies. How far these could go in giving rise to the higher compounds of the organic type experimentation has not yet satisfactorily determined. The analogy of the carbide action does not go very far, but it is something that it takes even a short step in the direction so characteristic of organic synthesis.

While the foregoing combinations and activities seem to us suggestive of the most favorable primitive conditions, they obviously do not warrant anything approaching an affirmation that organic synthesis really took place in this way in the soil, or that it is the offspring of inorganic antecedents solely. It has been our endeavor to trace the early terrestrial conditions and activities into as close an analogy to those that dominate the organic kingdom as present imperfect data permit. The conservative considerations that make it unsafe to assign organic genesis to an early terrestrial age without reserve, simply because it is not now in evidence, find their complement in withholding opinion respecting the possibility of such genesis by any combination of inorganic influences whatsoever, until it shall be experimentally settled. The great problem

must lie open yet awhile at least, but every line of approach, however hypothetical, may well be pursued if controlled by due reservations.

As remarked at the outset, many of these considerations are applicable to states of the earth which might have arisen at an early day under any of the cosmogonic hypotheses. We have given precedence to one of these hypotheses partly because it seems to merit a fuller exposition in this particular than it has received, and partly because it seems to us to present a physiographic setting more favorable for synthesis than would probably have arisen under the alternative cosmogonic hypotheses.

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UNIVERSITY REGISTRATION STATISTICS—I.

THE registration returns for November 1, 1908, of twenty-five of the leading universities of the country will be found tabulated on page 912. One institution has been added to the list this year, namely, Western Reserve University. A special effort was again made this year to prevail upon the reporting officers to do away altogether with the first item of double registration, but without complete success, and it must, therefore, be borne in mind that an institution with a large double registration in the fall enrollment naturally makes a comparatively better showing in the schools in which this duplication occurs, than one where this item has been reduced to zero. Furthermore, some difference of opinion evidently still exists concerning the proper classification of students enrolled in extension courses, evening courses, etc., for entrance upon which standards of admission are, to all intents and purposes, non-existent, and similarly there will be found in the summer session and even in regular

faculties, for example, in music and agriculture, students who have not completed a high-school course. Then again, a few institutions demand a baccalaureate degree or its equivalent for admission to one or more of their professional schools, as Harvard does for law, medicine, theology and engineering, Johns Hopkins for medicine, and Columbia for law, whereas at certain other institutions admission to the professional schools rests practically on a high-school graduation basis. Another factor that must not be overlooked is the difference in the number of partial students in attendance on various institutions: Columbia and Chicago, for instance, are apt to have more than Princeton or Stanford, and this circumstance should not be lost sight of in preparing figures intended to show the proportion of officers to students. All of these points are mentioned in order to emphasize once more the fact that the figures herewith presented have, from the very nature of the case, little qualitative significance, inasmuch as such items as standards of admission and advancement, efficiency of instruction, equipment, and the like, are necessarily ignored in the comparison. The figures have in every instance been furnished by the proper reporting officer, who has, in a number of cases, added interesting information about the development of the institution involved during the year just past.

Comparing the figures for 1908 with those of the previous year, it will be seen that, in spite of the prevailing economic depression, only two institutions, Harvard and Stanford, show a slight loss in enrollment, whereas two years ago five suffered a decrease. Taking the total attendance into consideration, *i. e.*, including the summer session, the greatest gains in terms of student units have been made by Chicago, Columbia, Wisconsin, Indiana, Pennsylvania,